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DAMAGE EVOLUTION IN FILLED ELASTOMERS

Final Report

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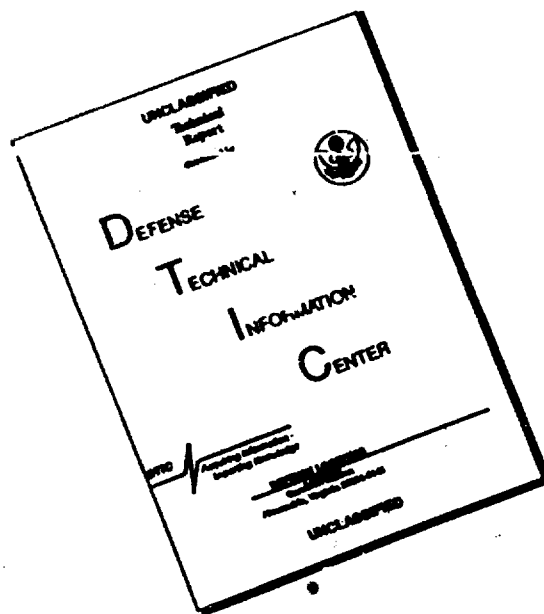
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This report summarizes accomplishments on the development of mathematical models of distributed microcracking in filled elastomers, such as solid propellant, and in other linear and nonlinear viscoelastic composite materials. The work is divided into two parts. The first part is concerned with elastic composites, while the second part extends the theory to viscoelastic behavior.

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SUMMARY OF WORK ACCOMPLISHED

This report summarizes accomplishments on the development of mathematical models of distributed microcracking in filled elastomers, such as solid propellant, and in other linear and nonlinear viscoelastic composite materials. The work is divided into two parts. The first part is concerned with elastic composites while the second part extends the theory to viscoelastic behavior.

Some comparisons between theoretical and experimental results have been made for elastic behavior. Sufficient experimental results on viscoelastic behavior were not available during the grant period, but it is planned to obtain such data as part of our work on the new grant.

(1) Damage Growth in Elastic Particulate Composites.

This work is detailed in Publication 1 given on page 4. In a portion of the work, a theory based on thermodynamics with internal state variables is used to mathematically characterize and then predict mechanical behavior of highly-filled rubber (solid propellant) with distributed microcracks. The effect of individual particles and microcracks is smeared out in that the composite is represented as a homogeneous continuum on a scale that is much larger than particle and crack sizes.

Experimental results and the theory for axially stretched and pressurized specimens are combined to derive three material functions of damage. The theory is then used to predict behavior under pressures not used in the development of the material functions. Good agreement between theory and experiment is shown for the strain range from zero to the zero-pressure failure strain of approximately 55%.

Major simplifying assumptions in this first part of the theory is that (1) only one internal state variable is needed to account for the damage, and (2) applied work is independent of strain history during a continuous damage growth process. These assumptions are supported by the available experimental data and a micromechanical model.

This micromechanical model is described and used in the second half of the paper. It is a so-called self-consistent model with one or two cracks adjacent to each (spherical) particle. The model is used to predict the same set of material property functions which were previously derived from experimental data and to predict stress-strain and dilatation-strain behavior. There are effectively only two free constants in the theory, the initial (linear) Young's modulus E and a dimensionless ratio, $\lambda = RE/G_c$, where G_c is the cohesive or adhesive fracture energy for microcracking and R is a characteristic particle radius. The predictions are in quite good agreement with the experimental stress-strain data and with the dilatation data at atmospheric pressure. With increasing pressure the theory over-predicts the dilatation somewhat by increasing amounts. However, the qualitative behavior is correct. The discrepancy appears to be due to crack orientation; all crack normals were assumed to be parallel to the axial (stretching) direction, while the experimental data seem to imply there is a moderate effect of off-axis cracks. Generalization of the theory to account for a distribution of crack orientations is planned for the new grant.

The micromechanical model gives the important result that damage is an increasing function of the parameter λ (at any given level of strain). Thus, a decrease in characteristic particle size or increase in fracture energy produces a reduction in damage. It is also shown that, as an approximation, the effect of the growth of many cracks of many different sizes may be accounted for through a single internal state variable, and that the total work of damage can be used as this variable. This prediction provides theoretical support to the assumption used previously in the analysis of experimental data.



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(2) Damage Growth in Viscoelastic Composites.

Details of this work are in Publication 2 on page 4. In this paper some analytical results are first reviewed for the overall mechanical behavior and damage growth exhibited by elastic composites. Extension of the theory to viscoelastic materials is then described. In general, the mathematical model for viscoelastic behavior could be extremely complex. Therefore, the emphasis of this work is on the development of a model in which physically realistic assumptions are used to simplify the theory.

The effect of strain rate on material behavior only at crack tips is considered first. It is shown that if the crack speed is a strong function of energy release rate (which is indeed the case for elastomers and many other polymeric materials), then the overall mechanical behavior is like that for an aging elastic material. It is shown that both stable and unstable microcrack growth produces this aging-like behavior. The material's "age" depends on current values of the applied loads, not past values, if the damage grows continuously. Past values of the loads enter in the model when the damage growth is not continuous, such as when there are periods of unloading.

Viscoelastic behavior throughout one or more of the constituents in the composite is introduced next. A simplification is used in which only one relaxation modulus characterizes the viscoelasticity, apart from that at crack tips. The theory shows that displacements in the previously developed model for "aging" elastic behavior may be replaced with convolution integrals of the physical displacements (called *pseudo displacements*). A mathematically simple representation for viscoelastic composites with growing damage is thus obtained. The theory still looks like that for an aging elastic composite, but the boundary displacements are pseudo displacements.

The theory developed on this grant is sufficiently general and complete to enable a detailed comparison with experimental results on mechanical behavior of solid propellant and to relate damage growth to loading history and to material parameters, such as microcrack fracture energy and characteristic particle size. This comparison and refinements to the model are planned for the new grant period.

PUBLICATIONS

1. Schapery, R. A., "Analysis of Damage Growth in Particulate Composites Using a Work Potential," Texas A&M Report MM 27010-90-10, August 1990. Published in Microcracking-Induced Damage in Composites, A.S.M.E. Book No. AMD-Vol. 111, 1990, pp. 55-64.
2. Schapery, R. A., "Simplifications in the Behavior of Viscoelastic Composites with Growing Damage," Texas A&M Report No. MM 27010-90-8, July 1990. Published in Inelastic Deformation of Composite Materials, Proceedings of an IUTAM Symposium, Troy, NY, 1990, pp. 193-214.
3. Schapery, R. A., "On Some Path Independent Integrals and Their Use in Fracture of Nonlinear Viscoelastic Media," Int. J. Fracture, Vol. 42, 1990, pp. 189-207. This paper covers work completed during the previous grant period.